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BARYON TRANSPORT IN DUAL MODELS AND THE POSSIBILITY OF A BACKWARD PEAK IN DIFFRACTION

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Dual string models contain significant baryon transfers and seem essentially consistent with the available data. We here turn to a careful consideration of the relevant topological structures. The baryon transfer is associated with one of two possible types of cuts in various baryonium exchanges. As the baryonium with the highest intercept easily couples to two Pomerons such transfers should occur abundantly in percolating dense Pomeron systems. From the color structure this quark-less baryonium can be identified with an Odderon exchange. As the Odderon is predicted to have an almost Pomeron-like trajectory it has to involve small coupling constants so that steeper trajectories can initially determine the data. As this suppression is not anticipated for diffractive processes a tiny observable backward peak should occur in the initial baryon distribution for massive diffractive systems.

Baryon transfer in particle scattering

The suppression of the long range transfer of baryon charges in inclusive spectra and in annihilation is in the range below $\sqrt{s} = 10$ GeV resp. $\Delta y = 2$ determined by a baryonium intercept of $\alpha_{Transfer} - \alpha_{Pomeron} = -1$ ^{1,2,3}. At the center of ISR^{4,5} there is an indication of a flattening. New preliminary data from the H1 experiment at HERA⁶ support this turnover. The trajectories required by a HERA ratio compared with its ISR value can be estimated as (see also⁷)

$$\alpha_{Transfer} - \alpha_{Pomeron} = -0.4 \pm 0.2.$$

Both obtained slopes correspond to the classical Dual Topological model⁸ expectation⁹ $\alpha_{junction}^I - 1 = -1.0$ and $\alpha_{junction}^0 - 1 = -0.5$ for both trajectories. However the value of the final trajectory is rather uncertain. Values of $\alpha_{junction}^0 - 1 = -0.8 \dots 0$ can be found in the literature^{10,11,12}.

Such baryonium trajectories are included in most fragmentation codes in a somewhat indirect way (see e.g.^{13,14,15}). The splitting functions usually contain all possible quark and diquark transition. It includes a pure diquark contribution which corresponds to baryonium cut. In the widely used JET-SET code¹⁶ the combinatoric suppression is tuned to yield effectively the initial steep slope.

Concepts for slowing-down initial baryons in heavy ion scattering

To understand the data it seems necessary to include interplay of string if they get sufficiently dense in transverse space. It was proposed that there

are new special strings^{17,18}. In contrast, we shall here maintain the general factorization hypothesis between initial scattering in the quark phase and the final hadronization within standard strings. Final state interactions are known to introduce some correction to the simple picture.

An obvious mechanism involves the incoming baryons. The usual Pomeron exchange in the Dual Parton model leaves a quark and a diquark for the string ends. Diquarks are no fixed entities and multiple scattering processes can split them in a conventional two Pomeron interaction^{19,7,20,21,22}. It is natural to expect that diquark break-ups considerably slow down the baryons evolving. The probability for such an essentially un-absorbed²³ process strongly depends on the density^{24,25,26,19}. As required by the experiment this is a drastic effect for heavy ion scattering¹⁹ while for hadron-hadron scattering multiple scattering is sufficiently rare to preserve the known hadron-hadron phenomenology²².

The behavior of the baryon quantum number slowed down by such a break-up is not trivial. In topological models the baryon contains Y-shaped color electric fluxes connected by a vortex line. The energy distribution of quarks with vortex lines (or of the fully separated vortex lines) in the structure function is a priory not known and requires special consideration.

Special baryon transfers in the Topological model

For this question we return to the Dual Topological model⁹ on which models like the Dual Parton model are based (for a recent discussion on baryonium see also²⁷) and emphasize topological aspects. The Pomeron exchange corresponds to a cylinder connecting the two scattering hadrons. On an arbitrary plane intersecting this t-channel exchange the intersection is topologically a circle. More specifically amplitudes with clockwise respectively anticlockwise orientation have to be considered and the cylinders or the circles come with two orientations. This distinction is usually not very important as it is always topologically possible to attach hadrons in a matching way. Except for C -parity conservation (which follows from cancellations) no special restrictions result.

Pomerons have a transverse extent and if they are close in transverse space they should interact. Hadronic interaction is sufficiently strong to be largely determined by geometry as long as there is no mechanism of suppression. It is therefore reasonable to expect that the coupling does not strongly depend on orientation.

The two distinct configurations occur. Two Pomerons with the same orientation can if they touch (starting locally at one point in the exchange-

channel time) shorten their circumference and form a single circle:

*0.50.03figure12.eps

This then corresponds to the usual triple Pomeron coupling experimentally well-known from diffractive processes.

For two Pomerons with opposite orientation the situation is more complicated. Like for soap bubbles the two surfaces which get in contact can merge and form a single membrane, starting locally with the creation of a vortex pair. The joining inverts the orientation of the membrane. On the intersecting plane one now obtains – instead of the single circle – three lines originating in a vortex point and ending in an anti-vortex point as shown below:

*0.50.03figure1.eps

Lacking a topological name for the object the term membraned cylinder will be used in the following.

How do this membraned cylinder contribute to particle production? Similar to the triple Pomeron case there are three different ways to cut through a membraned cylinder:

*0.220.05figure13.eps

The symmetric cut (numbered 1) which also intersects the membrane has vortex lines on both sides. They present a topological description of the baryon transfers considered above. By symmetry they contribute with a positive sign. Cuts which intersect only two sheets (numbered 2) contribute to the two string contributions. Their sign is unknown. As they contain a closed internal fermion (vortex line) loop we here assume a negative sign.

The identification with the Odderon

It is widely believed that calculable hard processes can be used as a guide to model corresponding soft processes as a suitable extrapolation.

The topological considerations in perturbative QCD are based on the $1/N_C$ - expansion. This approximation selects contributions according to the magnitude of their color factors reflecting "coloring" choices of suitably drawn color lines. For an amplitude of a given structure with a given number of couplings the leading order $1/N_C$ contribution can be drawn without crossing color lines. In special situations the drawing has to be done on topological structures which are more complicated than the simple plane considered above. An example is the cylinder which is assumed to be responsible for the Pomeron contribution.

The known example of the soft hard correspondence is the connection between soft and hard Pomerons. To identify the hard partner of the soft Pomeron we first observe that the simplest representation of a Pomeron in PQCD involves the exchange of two gluons which form a color singlet with the

required positive charge parity. Following this concept it can be shown²⁸ that a generalization of such an exchange gives the dominant contribution at very high energies in a well defined approximation. It is called “hard” or BFKL Pomeron and involves a ladder of two exchanged Reggeized gluons linked by a number of gluons. In the topological expansion the leading structure of a BFKL Pomeron corresponds to a cylinder. The two basic Reggeized gluons are exchanged on opposite sides parallel to the axis:

*0.330.05figure14.eps

Their matching inner color lines can be linked in front of the cylinder without color line crossing. Analogously their matching outer lines can be connected on the back of the cylinder.

Going back to the soft regime the basic assumption in topological models is that the $1/N$ -expansion stays valid and that the soft Pomeron therefore maintains its cylindrical structure needed for the two string phenomenology of hadronic final states. If cut, soft and hard Pomerons lead to similar two string final states. As difference it remains that the trajectory of the observed soft Pomeron is just shifted downward roughly by a third of a unit from hard Pomeron calculated in leading logarithmic approximation.

Can one find a similar connection for the membraned cylinder? The simplest representation spanning such a topological structure involves three gluons, one on each sheet exchanged parallel to the axis. Any gluon linking these exchanges has then to pass through a vortex line in which the three sheets join. In the $1/N$ expansion extended to baryons this means that the color lines have to cross passing this line. The basic QCD structure of the membraned cylinder exchange is therefore the following:

*0.332cmfigure16.eps

Looking from the other side a color singlet of three gluons can have the quantum numbers of a Pomeron or an Odderon²⁹. There is a simple topological property of the Odderon. A single uncrossed gluon link would project the color structure of the pair of exchanged Reggeized gluons to that of a single gluon, $(8)_F$, and the exchange would have to correspond to a Pomeron-like contribution. The Odderon will therefore have to involve crossed links. Hence it has exactly the topology of the membraned cylinder.

To visualize the baryonic color structure of the Odderon with its crossed exchanges one can replace the exchanged gluons by quark antiquark pairs without changing color lines. The so modified membraned cylinder just represents an exchanged baryon antibaryon pair.

In the QCD approximation used for the “hard” Pomeron the properties

of the “hard” or BKP Odderon³⁰ were calculated and the predicted intercept is 0.96³¹ or 1.0³⁴, depending of the details of the considered state. Again a mismatch between this hard leading logarithmic Odderon intercept and the possibly experimentally observed soft value by about a third is indicated by the data.

General consequences of membraned cylinder exchanges

Our preferred hypothesis is that the membraned cylinder exchange has a small or almost vanishing imaginary part. In this way there are no constraints from total cross section fits. Also, there is no coupling of the total C odd Odderon on a C even Pomeron pair. The cancellation allows a small or vanishing Odderon to contain sizable individual components of opposite sign, which (by looking at baryon exchange) can be used to determine the soft Odderon trajectory.

In heavy ion scattering where the Pomerons are dense in transverse space they can join and form a Pomeron or an Odderon. The individual strings are no longer independent but the general picture of particle production in separate universal strings survives. The probability of such an interaction of strings is growing proportional to the density and eventually to rapidity range. The transition from a Pomeron pair to the centrally cut membraned cylinder involves baryon antibaryon pair production, which should occur quite abundantly. Between a proton and Pomerons the cut membraned-cylinder is a very efficient mechanism of baryon stopping.

Both effects correspond to experimental observations. As the trajectory is not well determined it is hard to obtain really reliable quantitative estimates which can be tested convincingly with on heavy ion data.

The backward peak in diffraction and possibly in electro production

There is however a very specific qualitative prediction which can be tested. Consider a massive diffractive system. Usually the diffractively produced particles will originate in two strings of a cut Pomeron and the baryon charge will stay on the side of the initial proton. As usual there might be some migration to the center with a slope in rapidity eventually corresponding to the difference of the Odderon and the Pomeron trajectory. Topologically it involves a horizontal cut through the following structure:

*!0.08figurbarodd.eps

The high Odderon trajectory requires a clear suppression from the coupling constants to stay consistent with low energy data. The natural candidate for such a suppression is the Pomeron-Baryonium vertex, which involves no large overlap and for which cancellation between separate contributions can be expected. In consequence at a certain distance it should be more favorable

for the membraned cylinder to span the total diffractive region and to utilize the more favorable coupling to the two Pomerons. In this way the initial baryon will end up exactly at the backward end of the diffractive system.

*!0.19figure3.eps

It should be visible if one plots the rapidity distribution in relation to the inner end of the diffractive region, i.e. as function of $y_{\{Pomeron\}} = y_{\{CMS\}} - \ln(m\sqrt{s}/M(diffr.)^2)$. To illustrate the expected small backward peak we show the result of a calculation with the PHOJET Monte Carlo code³² of the incoming proton spectrum for diffractive events with a mass of 300 GeV for pp -scattering of 1.8 TeV with standard parameters below. To select diffractive events a lower cutoff of $x_F = 0.95$ was used. PHOJET contains diquark exchanges and yields reasonable baryon spectra in the forward region. To obtain the postulated backward peak we just mixed in a suitable sample of inverted events (with disabled diquark exchanges³³).

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